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FROM VEHICLE TO GENERATOR SET-DIESEL ENGINE VERSATILITY

Veneția SANDU[1]

Abstract: *The present paper continues the research work of converting commercial vehicle diesel engines into the prime mover of an apparent power of 267kVA generator sets. A V12 diesel engine was derated to 1500 rpm and adapted to the exigence of the generator set manufacturer. The redesign aimed to mitigate the dynamic engine cyclic unbalance expressed by the very low coefficient of speed fluctuations. By dynamometric brake testing, the engine was adjusted to deliver the prime rating power, proving its reliability, lower fuel consumption and lower noise.*

Key words: *diesel engine, coefficient of speed fluctuation, engine conversion.*

1. Introduction

There is a common practice of commercial vehicle manufacturers to adapt the diesel engines in other industrial applications such as generator sets, hydraulic pumps, compressors, railway or marine powertrains.

The generator sets engines can be easily and profitable converted from original heavy duty trucks and then calibrated for electricity generation, which means lower speeds and loads than the rated ones in automotive applications. Their use is typically required by emergency power supplies for strategic applications admitting no grid failure or for isolated applications with no access to power grid.

The power demand of the generator sets is different to the automotive powertrains; while the vehicle is dimensioned according to rated power at a rated speed, the generator works either at a continuous power called Load Continuous Rating (DIN 6271 A) or at emergency power called Prime Rating covering 10% power overload from continuous power, kept for short time intervals (DIN 6271 B) [5].

The conversion of a commercial diesel engine to a generator set imposes some changes in the engine design as well as the testing of some parameters, according to the demands of generator set manufacturer. Among the most important issues to adapt are the power delivery, variability of the engine speed, fuel consumption, exhaust smoke emissions, sound pressure level and engine reliability.

On the Romanian generator market, Electric Machine Woks [4] previously required automotive engines adapted to drive generator sets of 65 kVA (powered by engine 550-L6-DT),125 kVA (engine 1050-L6DT),155 kVA (engine 1380-V8-DT), as mentioned by author in [3]. Further increase of power was demanded up to power outputs up to 235 kW involving the use of a higher capacity engine.

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[1] Mechanical Engineering Dept., *Transilvania* University of Braşov.

This paper reports the research work performed to adapt the automotive diesel engine for a generator set, according to the specific demands of a customer, detailing the main steps of the project: analysis of design demand, designing/redesigning, engine adaptation and testing [8].

2. Engine Design Demands

Generator set requirements of the contractor have been imposed on the engine power adjustment to be done for Prime Rating operation mode stipulated in DIN 6271 B, for 1 hour of 10% overload out of 12 hours operation at continuous power:

- Load continuous rating 214 kW;
- Prime rating 235 kW, equivalent to rated power P_n;
- Rated speed 1500 rpm.

The quality of electric output in terms of sinusoidal pattern demanded limited variation of engine speed assessed through coefficient of speed fluctuation, δ, and other generator constraints such as:

a) permanent variation of engine speed, at load variation from rated load to idle and reversed, to be maximum 4.5% from rated speed;

b) permanent variation of engine speed, in percentages from rated speed, when the load variates from 0.5 P_n to idle and reversed, to be maximum 2.5%;

The specific fuel consumption at total load should not exceed 215 g/kWh.

The overall engine noise measured at 1 m distance around its surface should not exceed 100 dB (A).

The engine smoke emission at full load should not exceed 2.5 Bosch units.

3. Engine Preparation

3.1. Selection of the Engine

The rated power demand of 235 kW at speed of 1500 rpm requires the selection of a higher engine capacity which was manufactured at Roman Truck company; engine code was 2070 V12 DTGE representing engine total displacement of 20.7 liters, V configuration at 90° of 12 cylinders, diesel turbocharged engine (DT) used for generator sets (GE) [8].

The calculation of apparent electric power at terminals, P_{el}, of the generator is based on the Prime rating, assuming the mechanical efficiency of generator η_m to be 0.91 and power factor ($\cos\varphi = 0.8$). The resulted power represents the mean power delivered to consumers by the AC generator:

$$P_{el} = \frac{\eta_m P_n}{\cos\varphi} = \frac{0.91 \cdot 235}{0.8} = 267.3\,\text{kVA}\,. \quad (1)$$

As a consequence, the engine was adjusted to the prime rating power of 235 kW, including the fan drive, at 1500 rpm.

3.2. Calculation of the Coefficient of Speed Fluctuation

For generator sets is defined the coefficient of speed fluctuation, δ, based on instantaneous maximum, minimum and mean value of the angular velocities of the crankshaft during a complete cycle or two revolutions:

$$\delta = \frac{\omega_{max} - \omega_{min}}{\frac{\omega_{max} + \omega_{min}}{2}} = \frac{\omega_{max} - \omega_{min}}{\omega_{med}} . \quad (2)$$

The maximum value imposed within the project is $\delta = \frac{1}{200}$, so the value should be calculated based on engine balance. The coefficient of speed fluctuation can be calculated according to Equation (3) [2]:

$$\delta = \frac{8.2 \cdot 10^6 \cdot k \cdot P_i}{I_v \cdot n^3} , \quad (3)$$

with k - coefficient depending on number of cylinders (k = 0.005 for 12 cylinders), P_i - indicated engine power in horse power, HP:

$$P_i = \frac{P_n}{\eta_m} = \frac{235}{0.8} = 293.75\,\text{kW} \approx 400\,\text{HP} . \quad (4)$$

I_v - moment of inertia of the flywheel in kgf ms^2 and n - engine speed in rpm.

The calculation of the total moment of inertia of the flywheel (I_f = 6 kgf · m^2) includes also the attached masses of generator rotor (I_{gr} = 14.3 kgf · m^2), as well as the engine semicoupling (m_e = 40 kg and diameter D_e = 0.44 m) and the generator coupling (m_g = 56 kg and D_g = 0.44 m):

$$I_v = (I_f + I_{gr} + m_e \cdot D_e + m_g \cdot D_g)/4\,\text{g} = 1.04\,\text{kg} \cdot \text{m}^2 , \quad (5)$$

$$\delta = \frac{8.2 \cdot 10^6 \cdot 0.005 \cdot P_i}{I_v \cdot n^3} = \frac{8.2 \cdot 10^6 \cdot 0.005 \cdot 400}{1.04 \cdot 1500^3} = 0.0047 = 1/210 . \quad (6)$$

4. Engine Testing Procedures

A 2070 V12 DT engine, series 020, was prepared for testing on the DC 300 kW dynamometric brake at Road Vehicle Institute INAR, Brasov, being performed 100 hour running in and the adjustment of fuel flow rate for P_n = 235 kW at 1500 rpm [9].

During the tests the engine was operated without fan and compressor, at ambient barometric pressure 719 mm column Hg and average temperature 23 ºC. The engine performance was corrected with correction factors due to atmospheric conditions, according to standard [6]. The pressure loss on the test bench air intake was 2450 Pa and 2850 Pa on exhaust duct.

4.1. Prime Rating Power Adjustment

The fuel injection pump previously adjusted at the manufacturer according to automotive needs, was readjusted on the test bench by reducing the fuel flow rate until the reaching of prescribed power. The engine characteristic of speed at full load based on measured engine parameters is illustrated in Figure 1.

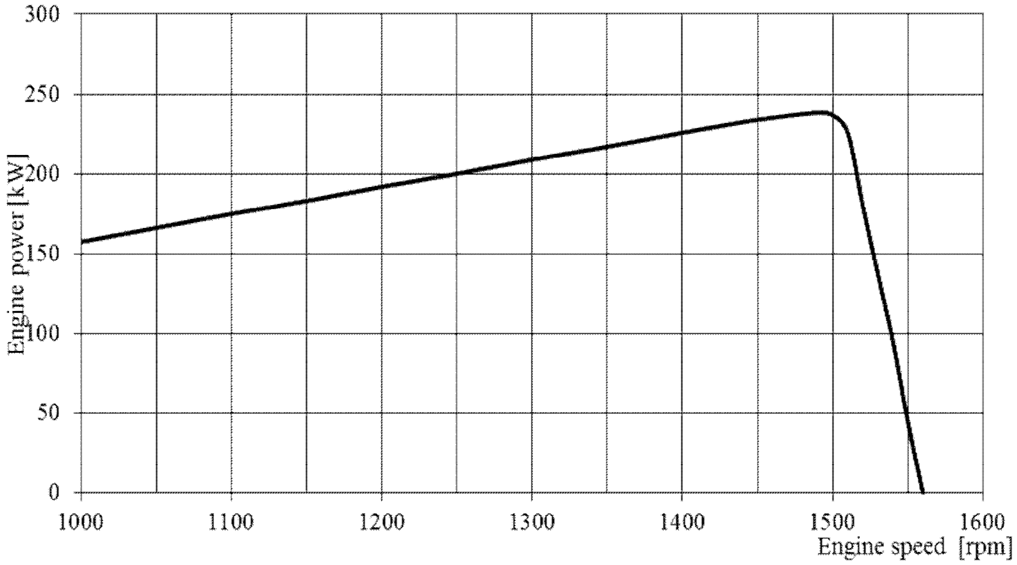

Fig. 1. *Full load speed characteristic*

The most important point of operation corresponds to rated speed at 1500 rpm and its power reached 236.7 kW, meeting the output of 235 kW imposed by project, within ±5% range.

4.2. Verifying Engine Speed Variability

The engine was run being measured the speed variability according to requirements imposed in Chapter 2, a-b.

a) The permanent variation of engine speed, at load variation from rated load to idle and reversed, was 60 rpm (4% from rated speed), lower than 4.5%;

b) The permanent variation of engine speed, when the load variates from 0.5 P_n to idle and reversed, was 35 rpm (2.3% from rated speed), lower than 2.5%.

4.3. Measurement of Fuel Consumption

There were measured three types of fuel consumption, one is the hourly fuel consumption of the engine at total load and the other is the specific fuel consumption which is calculated from hourly fuel consumption reported to rated power. The corrected values are presented in Figure 2; it can be noticed that the minimum specific consumption, 204 g/kWh, was adjusted to rated speed at 1500 rpm, being lower than 215 g/kWh limit.

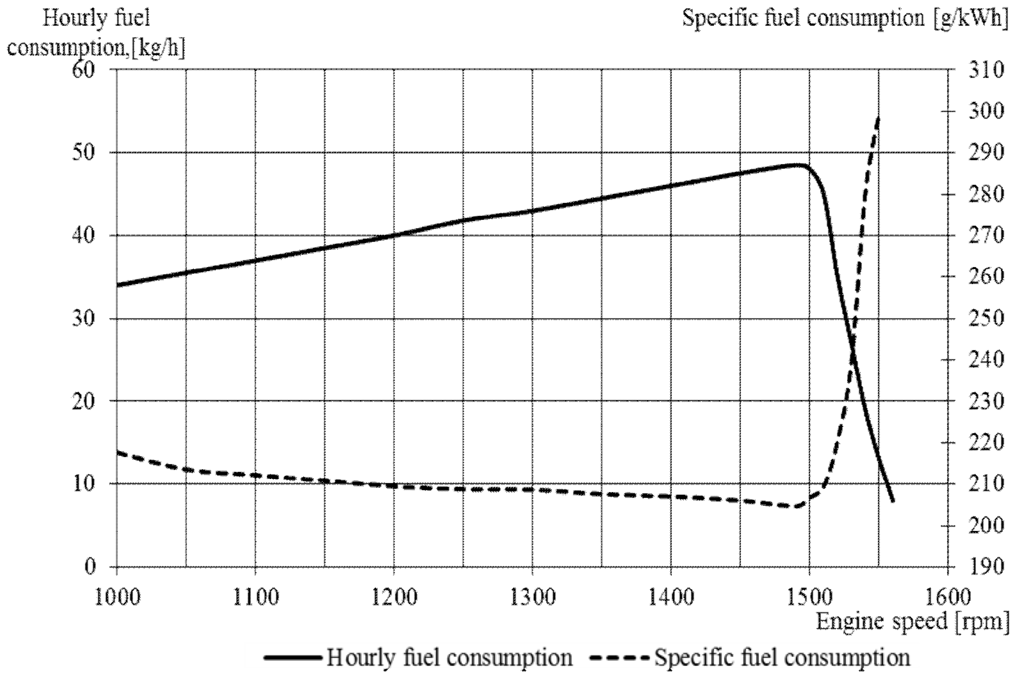

Fig. 2. *Hourly and specific fuel consumption versus speed*

The third type of fuel consumption is the idling hourly fuel consumption, specific to idling operation mode, without load, which is represented in Figure 3.

4.4. Reliability Testing

The reliability engine testing on the dynamometric brake includes a 100 hour run under the following steps:

- 8 hour operation at rated speed and 50% of rated power;
- 8 hour operation at rated speed and 80% of rated power;
- 84 hour operation at rated speed and rated power.

During the run, no faults were reported. Finally, the engine performances were measured again and the relative differences between the previous performances reported in Figures 1, 2 and 3 were under 2%.

4.5. Mechanical Efficiency

Mechanical efficiency of the engine represents the share of energy of combustion turned into component friction of parts or driving auxiliary systems. The experimental determination of the mechanical loss can be done on a dynamometric brake by driving the engine with a generator. The method is known as motoring and involves the electric drive of the hot engine and measurement of the resistant torque which is proportional to the mechanical power loss. Being known the rated power, the mechanical efficiency was calculated [1] and plotted in Figure 3:

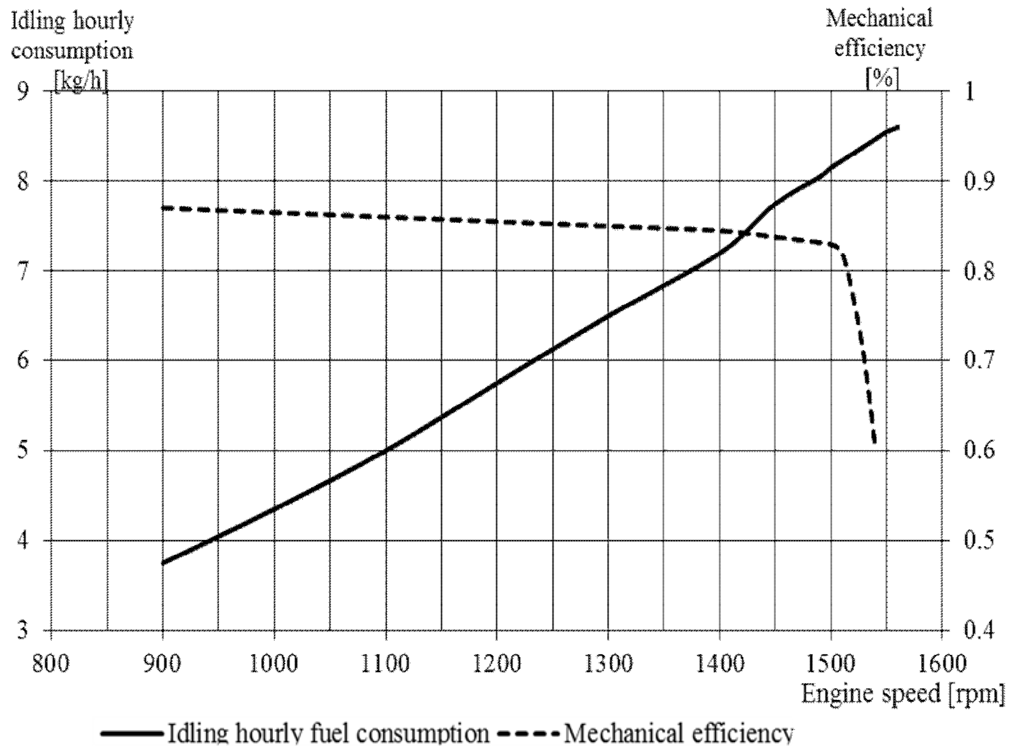

Fig. 3. *Mechanical efficiency and idling hourly fuel consumption versus speed*

The mechanical efficiency has the typical pattern of lowering with increase of speed until engine regulator operates, the numerical values complying with the usual interval 0.8-0.9.

4.6. Noise level

The experimental research was performed at full load on the same engine test bench placed in an acoustical treated testing room. The instruments included a Brüel & Kjær sonometer, first class of precision, real time analyzer, noise level recorder. The measurements met the second class of precision (technical methods). There were measured A-weighting Sound Pressure Levels (SPL) and Linear Sound Pressure Levels in eleven measuring points situated at 1m distance from engine surface and at 1m high above ground, as indicated in Figure 4.

In order to analyze the contribution of the dynamometric brake to the overall noise measurement, there were performed background noise measurements with dynamometric brake at speed of 1500 rpm, in points 1 and 9, the results being presented in Table 1.

Background noise levels Table 1

Measurement point	A-weighted SPL, dB	Linear SPL, dB
1	70.2	77.3
9	69.1	76.2

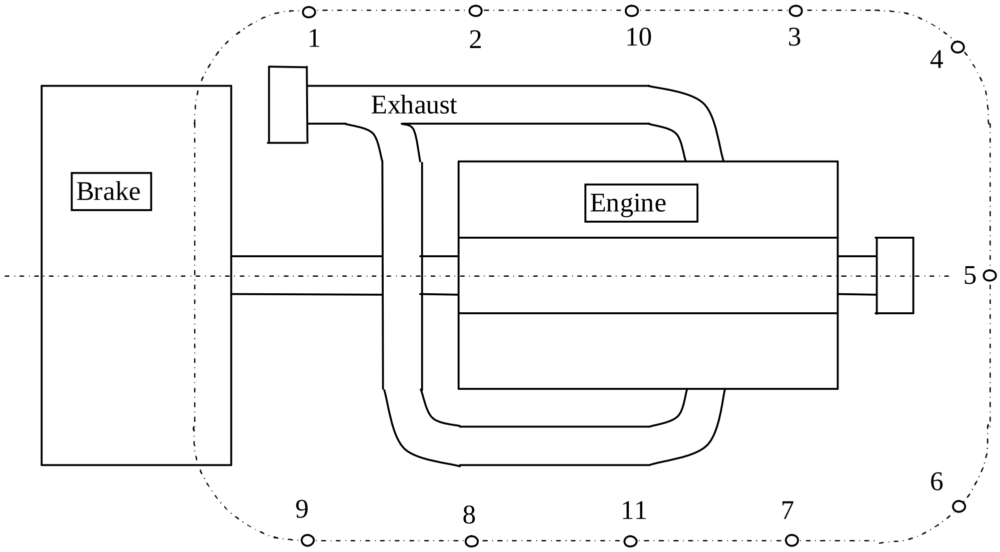

Fig. 4. *The configuration of noise measurement points*

The SPL values measured around the running engine at full load and speed are presented in Table 2.

Distributed noise levels Table 2

No of point	1	2	3	4	5	6	7	8	9	10	11	Total
A-weighted SPL, dB (A)	89	92.5	92.6	91	93.6	92.5	92.5	92.5	88.5	93	93	93
Linear SPL, dB	96.5	98.8	98.6	97	99.6	97.0	98.7	99.0	97.4	100	99	99

According to the addition logarithmic rule for SPL, the contribution of the background noise is around 0.1 dB so it can be considered negligible. The overall noise levels either weighted according to characteristics of human ear or in linear weight met the requirement imposed by generator designer.

4.7. Smoke Emission

The smoke emission was measured according to Regulation 24 [7] at full load on the whole range of speeds. The corrected values complied with the limit of 2.5 Bosch unit, as can be seen in Figure 5.

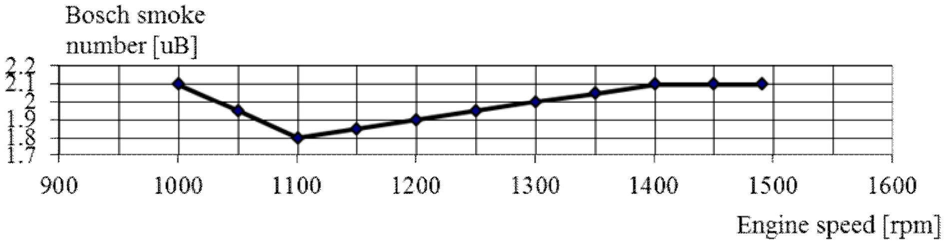

Fig. 5. *Smoke emission versus speed*

5. Conclusions

The high number of engine cylinders contributed to the fair dynamic balance of the crankshaft meeting the most difficult requirement on the generator speed fluctuation.

The commercial diesel engines proved to be versatile, easily adaptable to generator sets demands, fulfilling the expectations of the generator designer.

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